Project ID: EEMS002

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

SMART Mobility - Connected and Automated Vehicles

A Multi-Lab Coordinated Project

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2017 U.S. DOE Vehicle Technologies Office Annual Merit Review Meeting – June 6th, 2017

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

Overview

Timeline

- Project start date: Oct. 2016
- Project end date: Sept 2019
- Percent complete: ~20%

Highlighted Barriers

- **A:** Risk Aversion
- **F:** Constant advances in technology
- **E:** Computational models, design and simulation methodologies

Budget

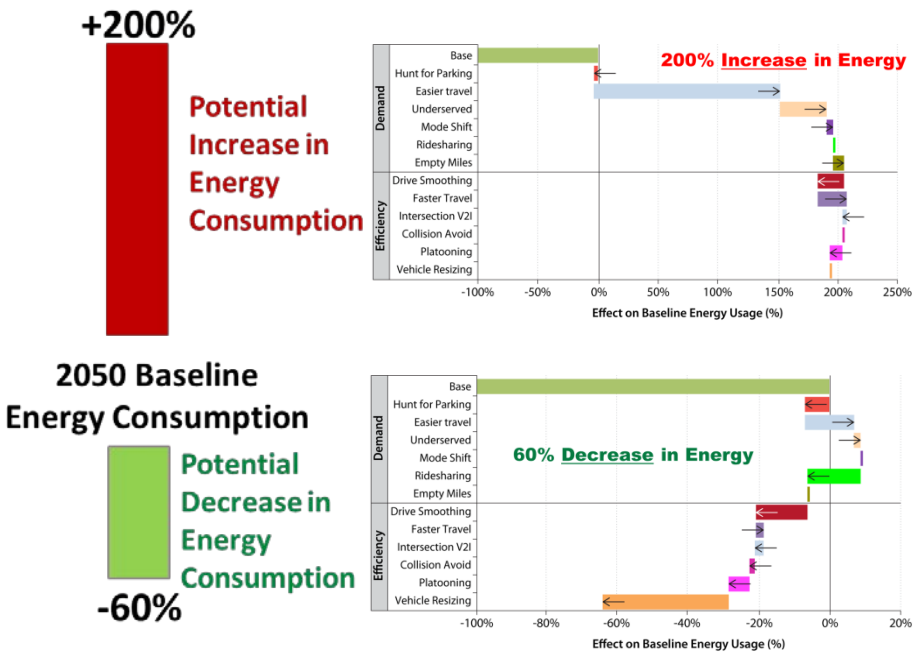
- Total project funding: $13.5M
- Funding for FY 2017: $4.5M

Partners

- SMART Consortium (ANL,INL,LBNL,NREL,ORNL)
- Volvo Car
- Volvo Truck
- DENSO
- Texas A&M University

Relevance - Fundamental Disruption is Occurring in Transportation

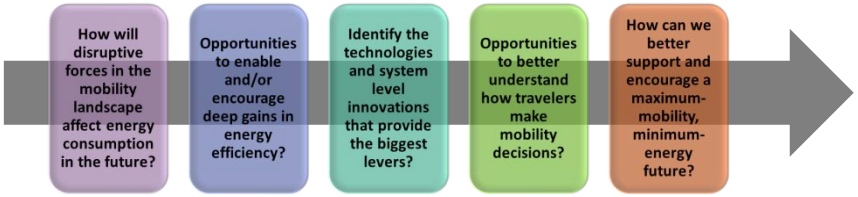
"Estimated Bounds and Important Factors for Fuel Use …of Connected and Automated Vehicles"



Building and expanding on the bounding analysis:

- Do "we" agree with the bounds?
- Under what conditions do the bounds occur?
- What are the intermediate states?
- How do Connected and Automated Vehicles (CAVs) integrate with other VTO technologies?

"A Maximum-Mobility, Minimum-Energy Future"



Source: Joint study by NREL, ANL, and ORNL: *http://www.nrel.gov/docs/fy17osti/67216.pdf*

Approach: Research Categories

1) CAV Assessment Framework Development and Evaluation

Developing and using a quantitative multi-scale, multi-fidelity analysis framework for CAV and transportation technologies and policies

2) Vehicle and System-level Optimization

Evaluating the unique vehicle and system-level opportunities afforded by CAVs

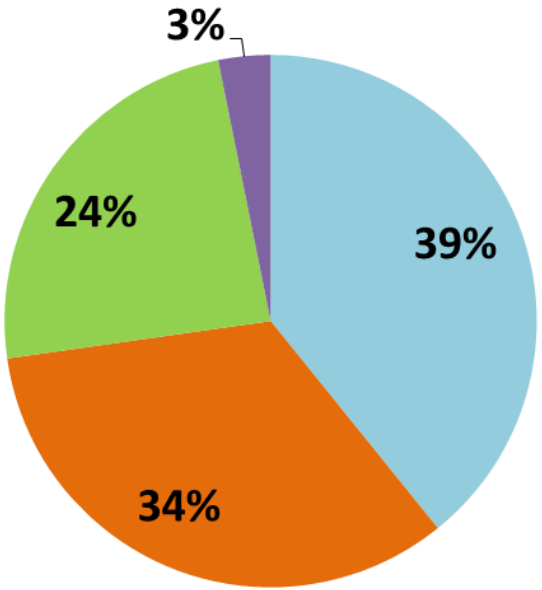
3) Living Lab: Data Collection and Experimentation

Collaborative data sharing and analysis of CAV research fleets and targeted experiments for insights and model validation

4) CAV Relevant Evaluation Procedures and Best Practices

Understanding select barriers associated with "eco" CAVs technologies

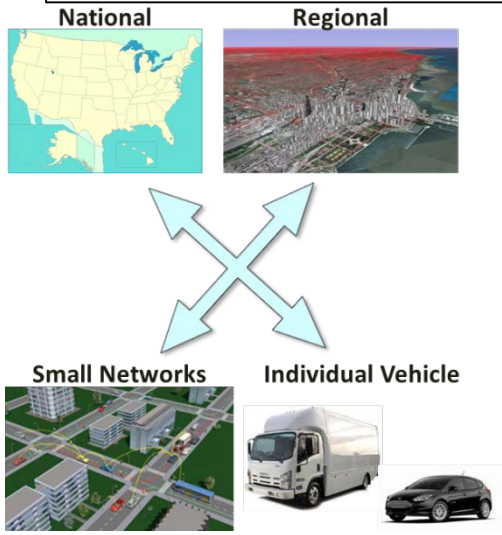
FY 17 Funding Allocation

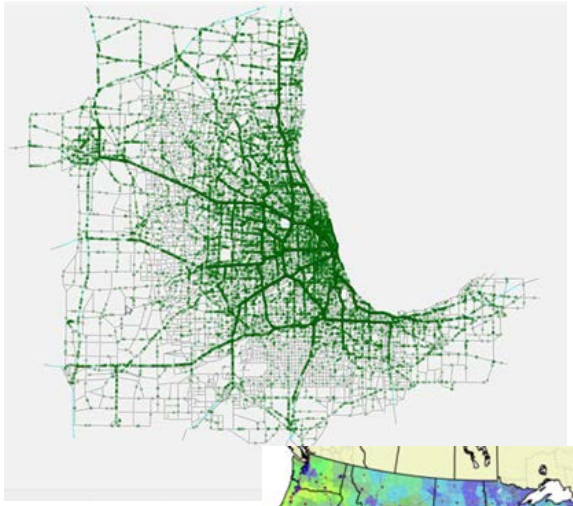


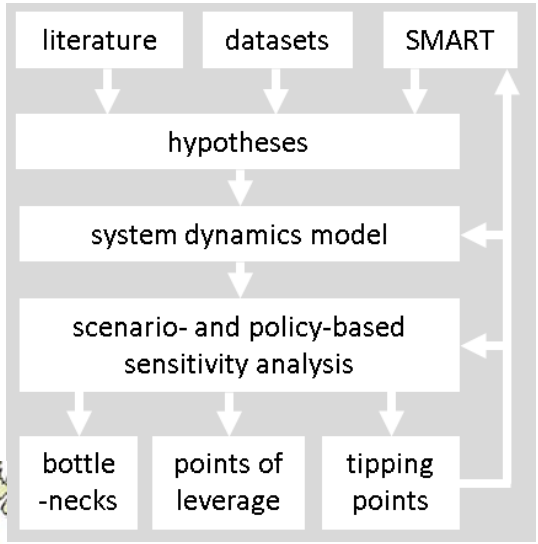
Approach - Focus 1 (mix of scales, approaches, and fidelity)

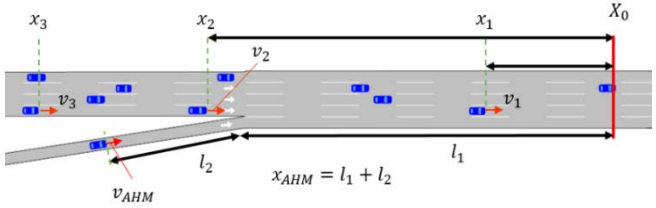
Focus 1 – CAV Modeling, Simulation, and Analysis Framework

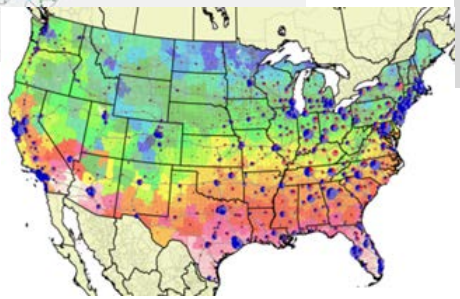
- Aggregation methods to estimate national-level impacts of CAVs Scenarios
- Common CAV technology concepts and time frames for adoption
- Traffic microsimulation of CAV concepts at various market penetrations
- Impact of CAVs on energy, GHG, and mobility in a metropolitan area
- System dynamics modeling of CAV adoption transitions and identifying tipping points







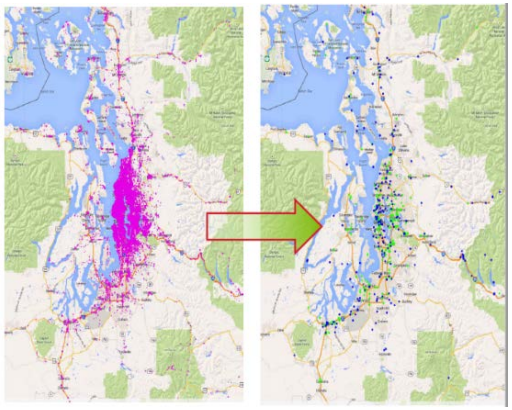


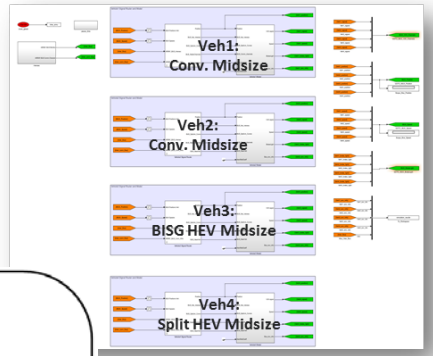


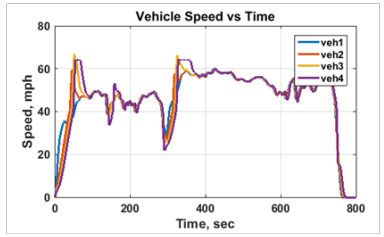
Approach - Focus 2 (leveraging information and control)

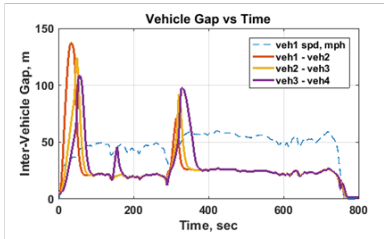
Focus 2 - Vehicle and System-level Optimization

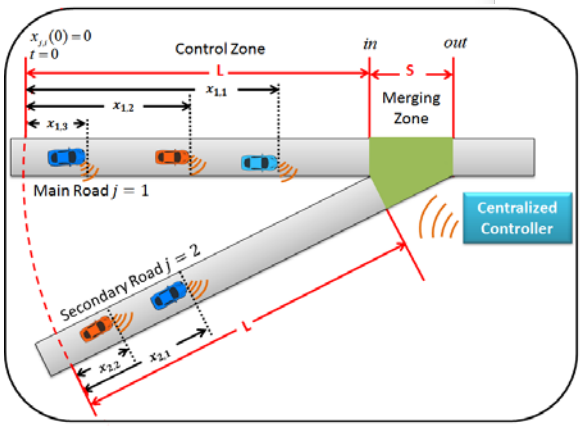
- Vehicle-to-Roadway-to-System-level, multi-scenario assessment of CAV system optimization opportunities
- Greater electrification and fuel switching possibilities due to vehicle and infrastructure connectivity and automation
- Optimal fleet rebalancing policies for an autonomous shared mobility system











$$u_i^*(t) = a_i t + b_i \rightarrow \text{Optimal Acceleration}$$

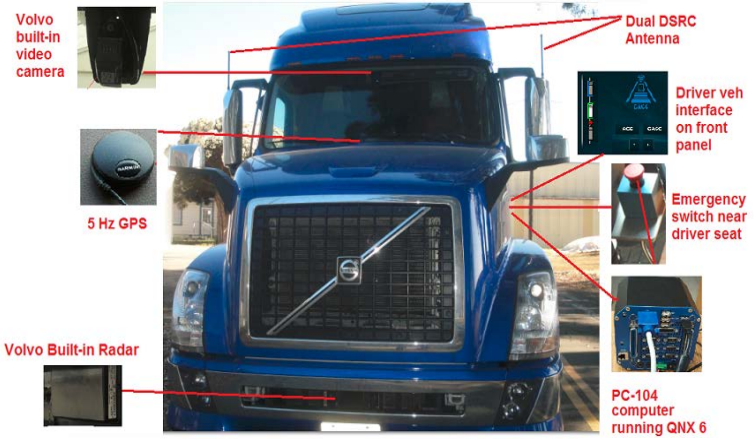
$$v_i^*(t) = \frac{1}{2} a_i t^2 + b_i t + c_i \rightarrow \text{Optimal Speed}$$

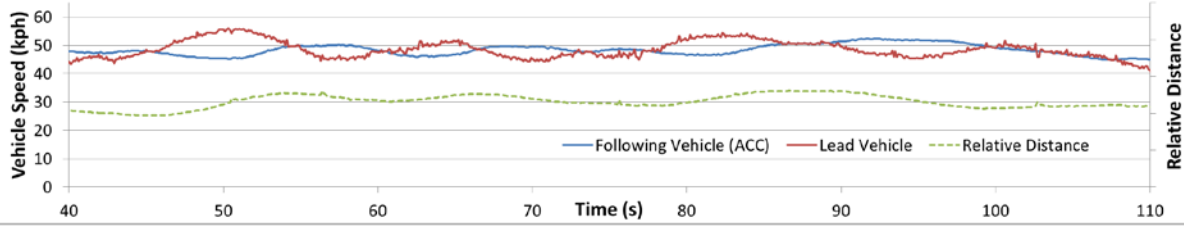
$$x_i^*(t) = \frac{1}{6} a_i t^3 + \frac{1}{2} b_i t^2 + c_i t + d_i \rightarrow \text{Optimal Position}$$

Approach - Focus 3 (living lab for research, data, and best practices)

Focus 3 – Living Lab: Research, Data Collection, and Experimentation

- Truck CACC/Platooning Testing: Measuring energy savings, interaction with aerodynamics changes, and impacts of control enhancements
- Develop and test passenger car CACC technology to quantify energy efficiency opportunities with experimental evaluation of Eco-Driving strategies
- Collection and analysis of CAVs-relevant real-world vehicle data
  - Volvo DriveMe CAV Pilot data collection partnership (ACC and automation)
  - Green routing in-field assessment and variability





Approach - Focus 4 (sharing best-practices, use cases, and data)

Focus 4 - CAV Relevant Evaluation Procedures and Best Practices

- Survey and relevance/gap-analysis of current vehicle charging, "performance" evaluation, and CAV system functionality assessment methodologies
- Identify and share best practices for CAV assessment, use cases, and data collection
- Challenges associated with data-sharing and management, out-reach, etc…

Understanding the Current FE/Energy Credit and Testing Environment

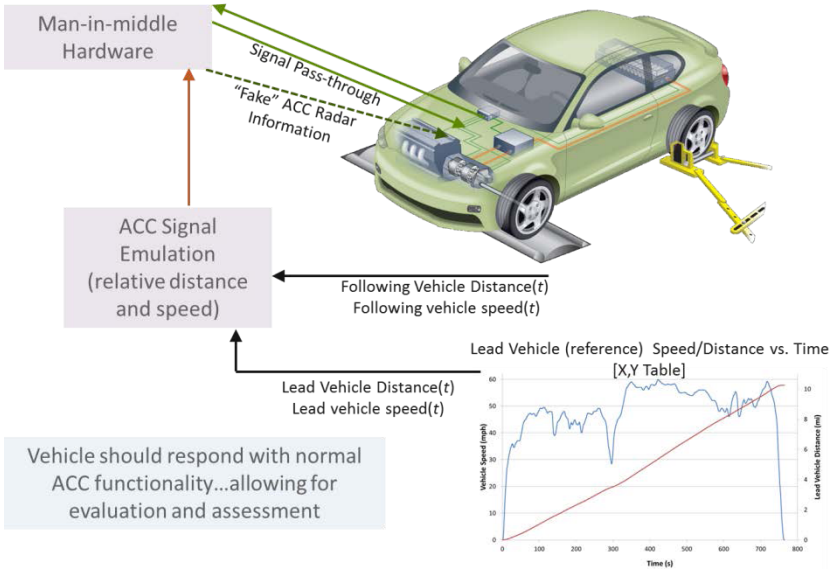
Identifying CAV supporting data needs and methods

Identifying Solutions/Challenges for More Robust Evaluation (on-road, track, dyno)

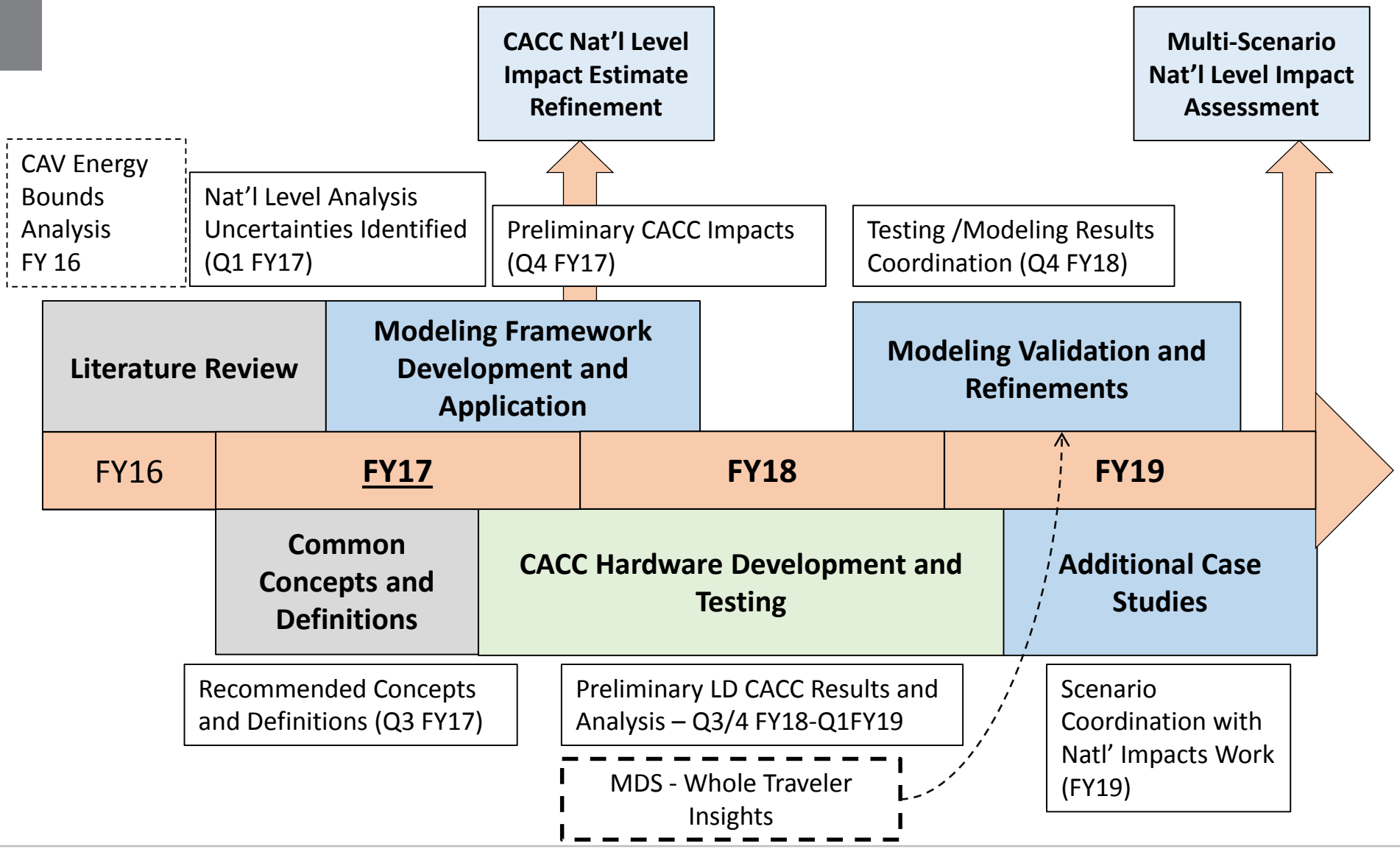
Evaluating Current Hardware Test Procedures for Gaps

Developing evaluation procedures to support DOE-CAV knowledge and data (what/where/how)

Helping inform stakeholders regarding CAV relevant issues



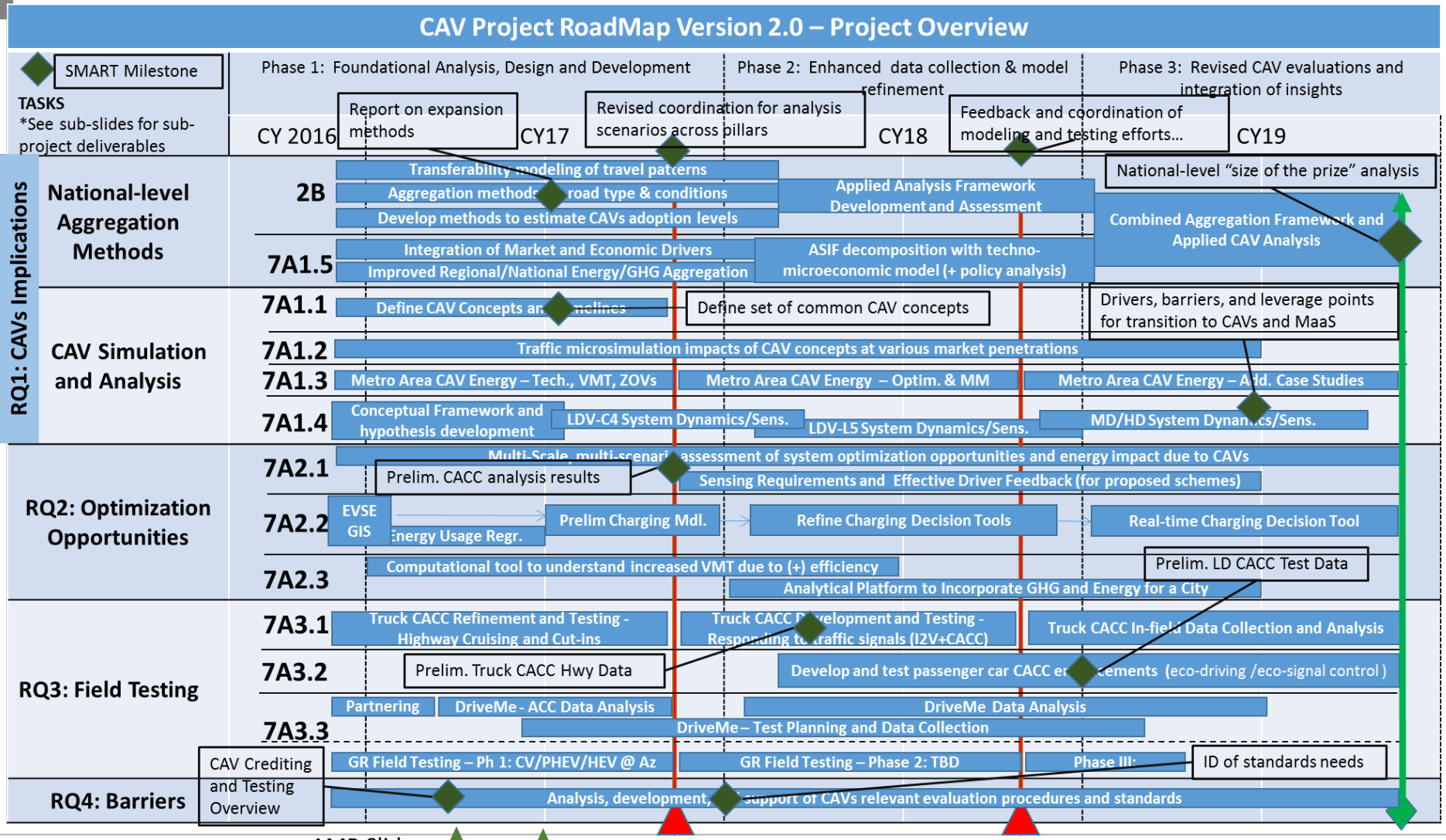
Example Approach: CACC Iterative Analysis Workflow Overview



Milestones and Project Overview

(yes, there are a lot of subprojects)

Working backward…tasks are building support and capability for national level "size of the prize" analysis including sensitivity

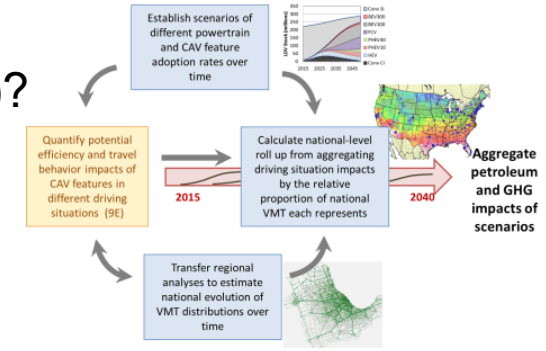


Accomplishments – Nat'l Level Analysis: Key Questions / Uncertainties Identified (Focus 1)

Light-duty vehicle key questions:

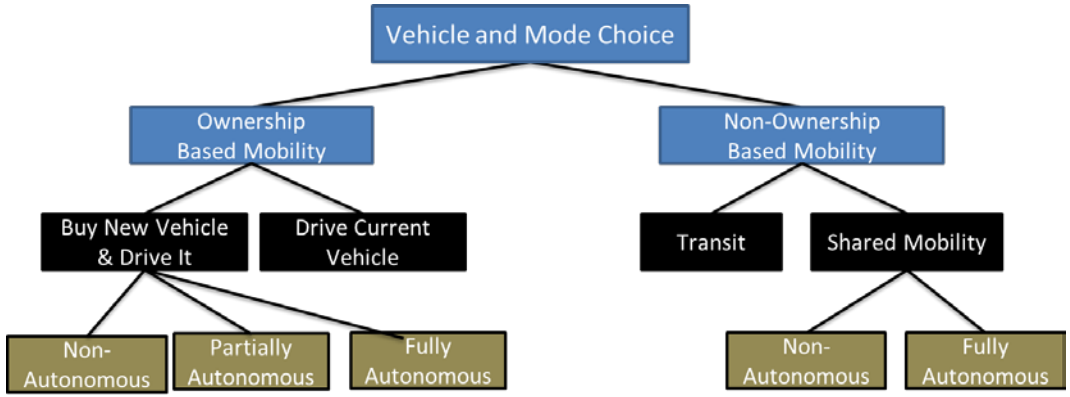
More details in EEMS026

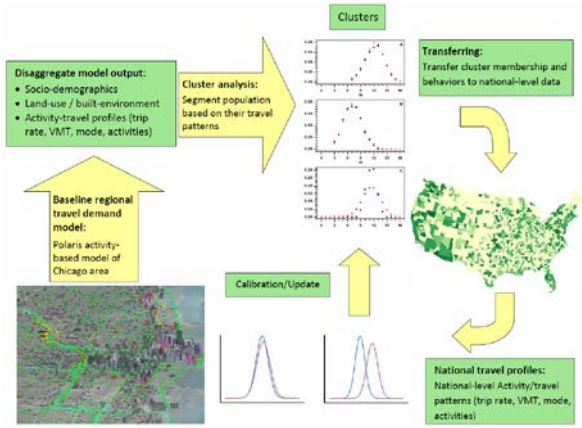
- How will travel demand change with CAVs?
- How will CAVs be adopted (what technologies, what level)?
- How will vehicle fuel economy change with?
- How CAVs can enable fuel switching?
- How to expand local/regional studies to national level?



Heavy-duty vehicle key questions:

- What is the energy impact of truck platooning/automation?



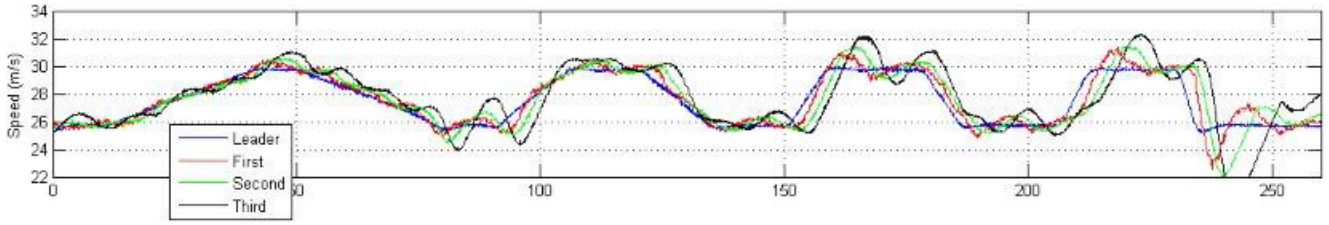


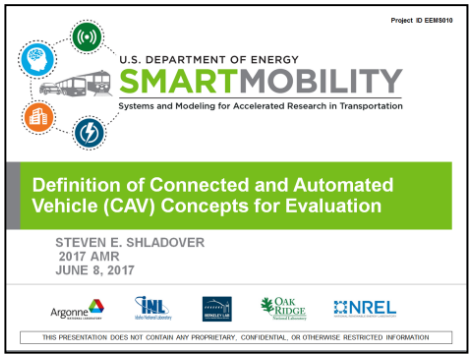
Accomplishments – Defined Concepts for Consideration Across SMART (Focus 1)

- I2V cooperative eco-driving guidance(L0)
- Laterally guided bus on busway (L1)
- Basic truck platooning (L1)
- Cooperative ACC or platooning for passenger cars (L1)
- Urban eco-signal control with I2V signal information (L1)
- Advanced truck platooning (L1 leader, L3/L4 followers)
- Highly automated bus on busway (L4)
- Semi-fixed route automated shuttle (L4)
- First-generation low-speed automated urban taxi (L4)
- Advanced automated taxi (L4)
- Low-speed urban goods distribution robot (L4)
- Urban freeway automated driving (L4)
- Automated highway system (L4 in dedicated, segregated lanes)
- Intercity freeway automated driving (L4)

The importance of concept definition (ACC vs CACC)…

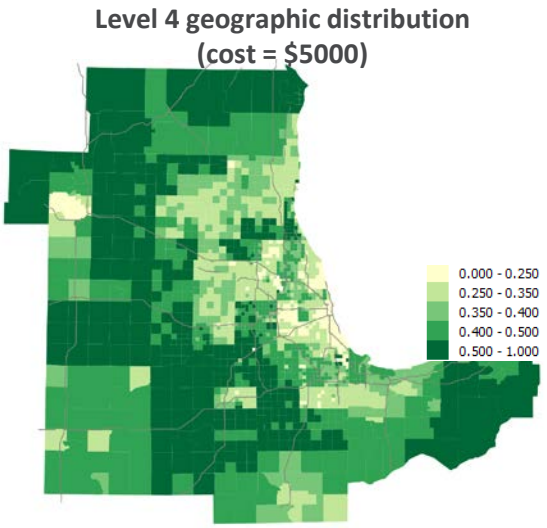
Production autonomous ACC response (4 vehicles – no connectivity):

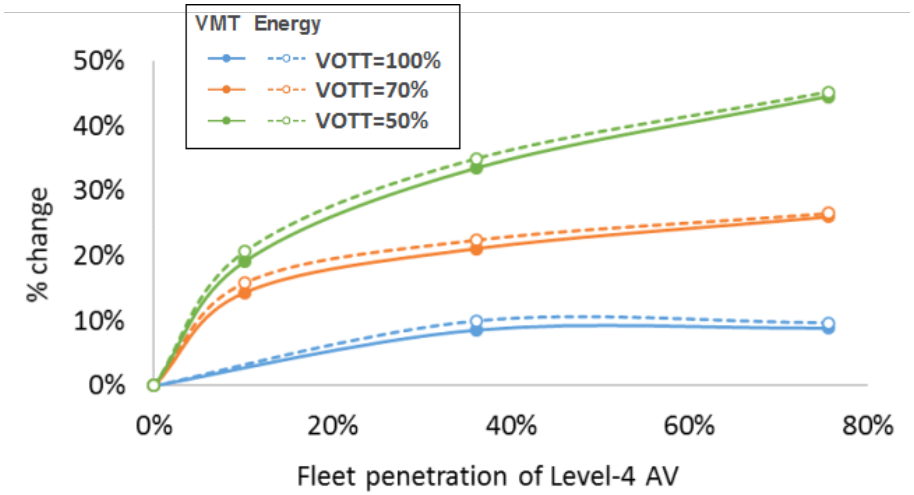




Accomplishments – Evaluated Impact of CAVs on Travel Demand at the Regional Level (Focus 1)

- Approach: model the impact of CAVs on both demand and operations
- Improved **POLARIS behavior** and **traffic flow** model:
  - Vehicle-choice model to assign CAVs to particular households
  - Various scenarios for Value of Travel Time (VOTT) based on literature review
- Updated traffic flow model to dynamically change each segment capacity based on the number of CAVs present on that link
- Performed a **case study** for Chicago metro area, with 30% and 50% reduction of VOTT, and CAV penetration levels up to 75%; **up to 40% fuel consumption increase** due to higher VMT cases
- Future FY17 work will focus on **traffic flow** model, and incorporating **energy effects** of CAV driving (e.g. aero)



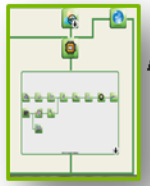


More details in EEMS017

Accomplishments – Framework for Integrated Powertrain-CAV Simulation and Control Development (Focus 2)

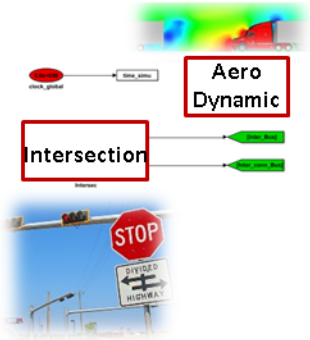
- Developed a Simulink-based framework that reuses **Autonomie** powertrain models and includes models of **intersections**, **human** driving, connectivity-influenced, and **automated** driving
- Applying **optimal control theory** to velocity-powertrain control problem for maximum energy savings

More details in EEMS016

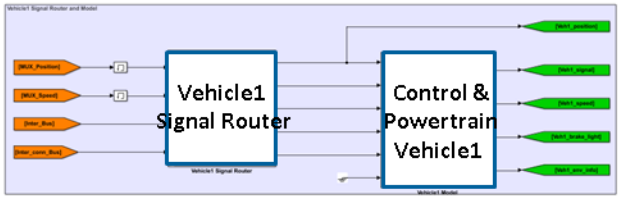


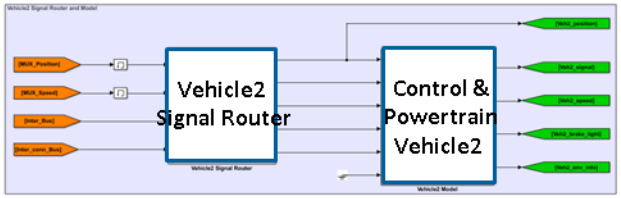
Autonomie Vehicle Models

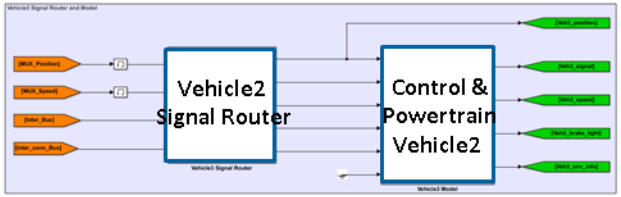
Automatic building of intersections



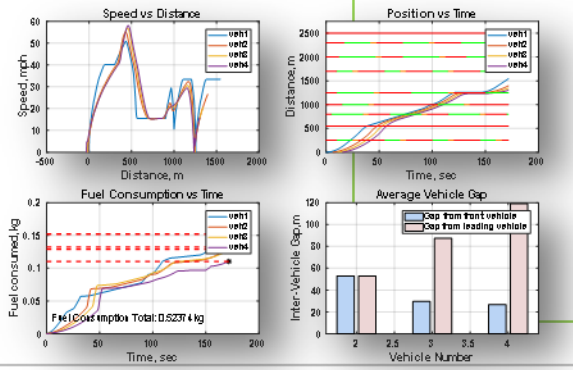
Co-simulation of High Fidelity Vehicle Models





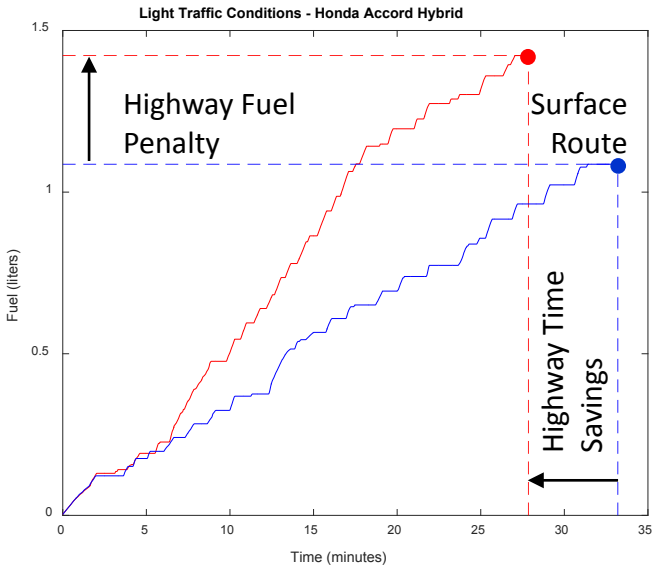


Visualization & results



Accomplishments - Green Routing Instrumentation Shakedown (Focus 3)

- Trips were taken between a fixed Origin/Destination pair using two different route types: Surface and Interstate
- GPS data were collected with fuel usage and ambient conditions
- Pairs were run simultaneously with two identical vehicles in light and heavy traffic conditions
- Data will be integrated into NREL green routing modeling tools to refine model



Accomplishments - CAV Testing and Crediting Snapshot (Focus 4)

How can SMART efforts expand the discussion from collision avoidance only and into the efficiency space…

- Off-cycle credits appear to be the most likely location for CAVs crediting
- "Indirect" improvements currently not considered
- 3/6/9 gCO_2/mi have been proposed for collision avoidance technologies (ADAS/DSRC/Both)
- **Can a mix of simulation, field, and laboratory work help support efficient evaluation CAV technologies?**

"Challenges to quantifying the effect on fuel economy of GPS/real time traffic navigation systems"

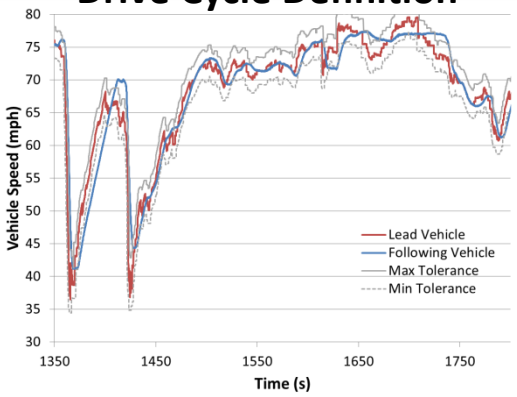
1) Service for the useful life
2) Routes actually improve FE
3) Proven accurate traffic info.
4) Use of eco-routing
5) Other sensitivities

Can SMART efforts aid in the "formidable" data burden for O.C. credits?

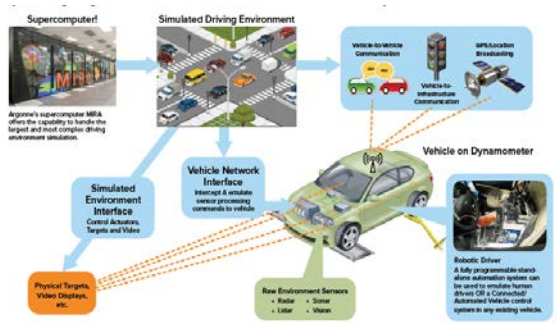
Highlighted Hardware Testing Investigations

- What is the difference between drive profile smoothing and an entirely new trip profile?
- How to expand the evaluation environment to broadly encompass CAV functionality?

Drive Cycle Definition



Expanded Environment



Partners/Collaborators

National Laboratory Partners:

- Primary Participants: ANL, INL, LBNL, NREL, ORNL in coordination with CAVs and other DOE SMART Mobility pillars: AFI, CAVs, MDS, US

University Partners:

- Texas A&M University

Industry Partnerships:

- Volvo Car – Collaboration with DriveMe Vehicle Pilot
- Volvo Truck – Truck CACC and platooning work
- DENSO - Supplemental instrumentation for Truck CACC work

Government and Metropolitan Partnerships:

- City of Columbus: Participation on SMART Columbus working groups and ultimately transfer of data/analysis/best-practices
- DOE-DOT MOU

Highlighted Future Research

Focus 1 - CAV Assessment Framework Development and Evaluation

- Continued development and coordination (where possible) of CAV assessment framework tools and methodologies
- Application of expansion and adoption methodologies to develop national-level estimates of CAVs energy use impacts (FY19 milestone)
- Microsimulation refinements to incorporate CAVs (FY17 and FY18 milestones)
- Expanded CAV impacts at the metro-level (FY18 milestones)

Focus 2 - CAV Assessment Framework Development and Evaluation

- Case study: Connected traffic signal intersection eco-approach for various powertrains
- Continued optimization development and evaluation at the vehicle-to-system level across a range of powertrains and vehicle usage missions

Focus 3 - CAV Assessment Framework Development and Evaluation

- Truck and light-duty CACC and platooning field experiments and analysis
- Data collection and analysis of DriveMe pilot data and expanded green-routing assessment work

Summary

Relevance

- How do connected and automated vehicle technologies fit into the "Maximum-Mobility, Minimum-Energy Future" for transportation systems…

Approach

- CAVs pillar builds upon bounding and other foundational work to focus on how, why, when, what…across a range of technical and behavioral scenarios and outcomes.
  1) CAV Assessment Framework Development and Evaluation
  2) Vehicle and System-level Optimization
  3) Living Lab: Data Collection and Experimentation
  4) CAV Relevant Evaluation Procedures and Standards

Highlighted Accomplishments

- Nat'l Level Analysis Key Questions / Uncertainties Identified
- CAV Testing and Crediting Snapshot
- Example Concepts Recommended for Consideration Across SMART Analysis
- Mesoscopic Simulation Improvements and Preliminary Case Study Results
- Framework for Integrated Powertrain-CAV Simulation
- Green Routing Instrumentation Shakedown